

ANALYSE DES DONNEES COMBINEES SLAC-BCDMS-NMC A GRAND x : α_s ET "HIGH TWISTS".

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Nous avons fait une analyse en QCD, a NLO l'approximation, de la combinaison des data de cross-sections profondes non-élastiques SLAC-BCDMS-NMC avec détermination de α_s . Nous montrons que la valeur obtenue pour α_s dépend de la procédure statistique du traitement des erreurs systématiques. L'ajustement des données avec la prise en compte complète des corrélations point-a-point donne une valeur $\alpha_s(M_Z) = 0.1183 \pm 0.0021(exp.) \pm 0.0013(echellederen.)$ compatible avec les mesures de LEP et la moyenne mondiale. Nous avons extrait d'une façon indépendante des modèles les contributions "high twist" aux fonctions de structures F_L et F_2 : la contribution de "twist-4" a F_L est en qualitatif accord avec les prédictions du modèle "renormalon" infrarouge; celle de " twist-6" a F_L tend faiblement vers les valeurs négatives et celle de "twist-6" a F_2 vers les valeurs positives, quoiqu'elles soient toutes les deux compatibles avec zero compte tenu des erreurs.

COMBINED ANALYSIS OF SLAC-BCDMS-NMC DATA AT HIGH x : α_s AND HIGH TWISTS

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We perform a NLO QCD analysis of the nonsinglet part of the combined SLAC-BCDMS-NMC data on inclusive deep inelastic cross section with the extraction of α_s . We show that the value of α_s obtained in the analysis is sensitive to the statistical inference procedures dealing with systematic errors on the data. The fit with the complete account of point-to-point correlations of the data gives the value of $\alpha_s(M_Z) = 0.1183 \pm 0.0021(\text{exp.}) \pm 0.0013(\text{ren.scale})$ that is compatible with the LEP measurements and the world average. Model independent x -shape of high twist contributions to the structure functions F_L and F_2 is extracted. Twist-4 contribution to F_L is found to be in qualitative agreement with the predictions of infrared renormalon model. Twist-6 contribution to F_L exhibit weak trend to negative values, and twist-6 contribution to F_2 - to positive values, although both are compatible with zero within errors.

Data on deep inelastic scattering (DIS) of charged leptons off fixed targets^{1,2,3} are an unique source of information about nucleon structure and value of strong coupling constant α_s . These data are obtained using high integral luminosity samples and their typical statistical errors are $O(1\%)$. However the experimental uncertainties are dominated by systematic errors that typically are 2-3 times as statistical ones. Systematic errors are more difficult to be accounted since they are correlated and an estimators which involve correlated data are complicated. This is the reason, why in many analysis systematic errors are accounted using simplified approach and/or partially (or even completely) ignored. The aim of our present study is to perform QCD analysis of the data from Refs.^{1,2,3} with a particular attention to thorough account of point-to-point correlations due to systematic errors. A reliable estimate of α_s implies the study of possible influence of high twist (HT) contribution to the scaling violation. In our analysis we perform simultaneous and model independent extraction of HT contribution to F_L and F_2 and study their correlations with the α_s value.

To allow for extraction of F_L we analyzed the data on cross sections separated by the beam energies instead of merged data on F_2 . We imposed a cut of $x \geq 0.3$ to prevent additional uncertainties due to a poorly known gluon distribution. This cut leaves data that to a good approximation can be described by the pure nonsinglet structure functions, which essentially reduces the number of fitted parameters. The cut $x \leq 0.75$, omitting the region where the binding effects in deuterium are large was also imposed in the analysis. The total number of the data points (NDP) left after the cut is 1243; the Q^2 range of the data is $1 \text{ GeV}^2 < Q^2 < 230 \text{ GeV}^2$; the total number of independent systematic errors is 47.

The QCD input leading-twist (LT) structure functions of the proton and neutron were

parametrized at the starting value of $Q_0^2 = 9 \text{ GeV}^2$ as follows: ^a

$$F_2^{p,n}(x, Q_0) = A_{p,n} x^{a_{p,n}} (1-x)^{b_{p,n}},$$

and then were evolved over the region of Q^2 occupied by the data in NLO QCD approximation in the \overline{MS} factorization scheme ⁵ with the help of the code used earlier. ⁶ The final formula for the structure functions used in the fit, with account of the twist-4 contribution was chosen in an additive form

$$F_{2,L}^{(p,d),HT}(x, Q) = F_{2,L}^{(p,d),TMC}(x, Q) + H_{2,L}^{(p,d)}(x) \frac{1 \text{ GeV}^2}{Q^2},$$

where $F_{2,L}^{(p,d),TMC}(x, Q)$ are given by NLO QCD with the account of target-mass correction. ⁷ The functions $H_{2,L}^{(p,d)}(x)$ were parametrized in a model-independent way: their values at $x = 0.3, 0.4, 0.5, 0.6, 0.7, 0.8$ were fitted; between these points the functions were linearly interpolated. The data on differential cross sections were fitted using the formula

$$\frac{d^2\sigma}{dxdy} = \frac{4\pi\alpha^2(s-M^2)}{Q^4} \left[\left(1-y - \frac{(Mxy)^2}{Q^2}\right) F_2^{HT} + \left(1-2\frac{m_l^2}{Q^2}\right) \frac{y^2}{2} (F_2^{HT} - F_L^{HT}) \right],$$

where s is total c.m.s. energy, m_l is scattered lepton mass and y is lepton scattering variable.

To take into account the point-to-point correlations of the data points we minimized a functional

$$\chi^2 = \sum_{K,i,j} (f_i/\xi_K - y_i) E_{ij} (f_j/\xi_K - y_j),$$

where K runs through the data subsets obtained by separation of all analyzed data on experiments and targets, and i through data points within these subsets. The matrix E_{ij} is the inverse of the covariance matrix $C_{ij} = \delta_{ij}\sigma_i\sigma_j + f_i f_j (\vec{s}_i^K \cdot \vec{s}_j^K)$, and each vector \vec{s}_i^K includes all independent systematic errors for the K -th data subset. The other notations are: y_i = the measurements; σ_i = the statistical errors; f_i = the theoretical model prediction depending on the fitted parameters. The normalization factors ξ were fitted for old SLAC experiments and fixed at 1 for BCDMS, NMC, and SLAC-E-140.

The results of this fit are given in Fig. 1. In view of large errors of $H_L^P(x)$ we imposed the constraint $H_L^P(x) = H_L^D(x)$ in the final fit. The statistical quality of the fit is acceptable: $\chi^2/\text{NDP} = 1255/1243$. The value of strong coupling constant obtained is $\alpha_s(M_Z) = 0.1170 \pm 0.0021(\text{stat+syst})$ that correspond to $\Lambda_{\overline{MS}}^{(3)} = 337 \pm 29(\text{stat+syst}) \text{ MeV}$ or $\Lambda_{\overline{MS}}^{(4)} = 301 \pm 30(\text{stat+syst}) \text{ MeV}$. Pure statistical error of $\alpha_s(M_Z)$ is 0.0011, which gives only small contribution to the total experimental error. The average bias of the the fitted function against data, calculated as $\left\langle (f - y) / \sqrt{\sigma^2 + f(\vec{s})^2} \right\rangle$ is 0.07 that is within its possible statistical fluctuation.

The correlation of α_s with the HT contribution to F_2 is very large (typical values of correlation coefficients is about -0.9). This means that separation of logarithmic and power effects in the analysis of scaling violation, which is based on the SLAC-BCDMS-NMC data without Q^2 cut, is unstable under various assumptions. In particular, the complete account of point-to-point correlations of the data leads to a shift of the α_s value by about 3 standard deviations from the results obtained using a simplified statistical inference procedure. ⁴ Since the HT contribution and the value of α_s are strongly anticorrelated, the increase of α_s is accompanied by a decrease of HT. ^b The total effect on the HT magnitude is about a factor of 3/4, as compared with the results of Ref. ⁴. At the same time H_L is almost uncorrelated with α_s , i.e. its value is less model

^aWe checked that extra polynomial-type factors do not improve the quality of the fits.

^bThis effect was also recently observed in the analysis, ⁹ where $\alpha_s(M_Z)$ was fixed at 0.120.

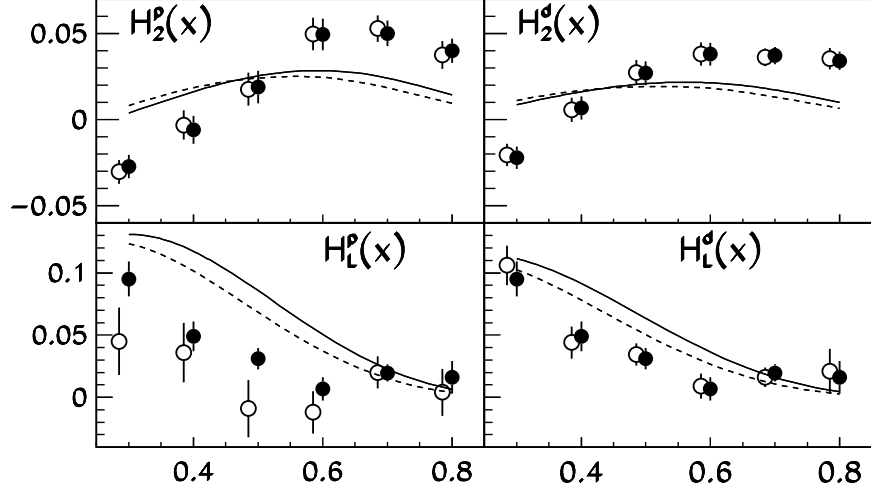


Figure 1: The fitted values of $H_2(x)$ and $H_L(x)$ (full circles – the fit with constraint $H_L^D(x) = H_L^P(x)$, empty circles – the unconstrained fit). The curves are predictions of IRR model for $Q^2 = 2 \text{ GeV}^2, n_f = 3$ (full lines) and $Q^2 = 9 \text{ GeV}^2, n_f = 4$ (dashed lines).

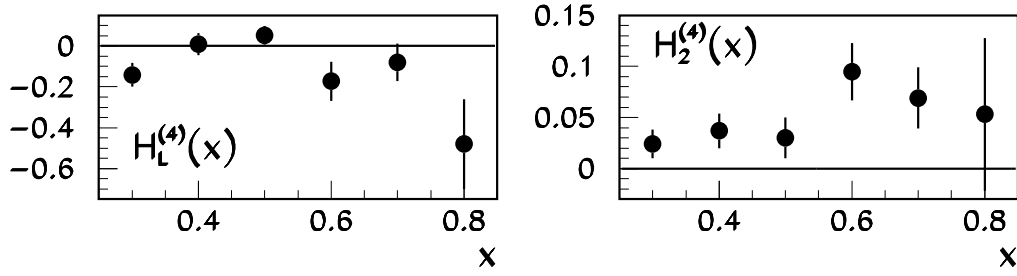


Figure 2: The dependence of twist-6 contributions to F_L and F_2 on x .

dependent. The predictions of infrared renormalon (IRR) model⁸ are also given in Fig. 1. The normalization factor A'_2 was chosen in the universal form: $A'_2 = -\frac{2C_F}{\beta_0}[\Lambda_R]^2 e^{-C}$ where $C_F = 4/3$, $C = -5/3$, $\beta_0 = 11 - 2/3n_f$, $\Lambda_R = \frac{\Lambda_{\overline{MS}}^{(3)}}{337 \text{ MeV}}$, as obtained in our analysis. One can see that the model qualitatively describes the data on $H_L(x)$ and there is evident discrepancy with the data on $H_2(x)$.

We checked how much the analyzed data are sensitive to the twist-6 contribution to F_L and F_2 . For this purpose we added to F_2^{HT} or F_L^{HT} the terms $H_{L,2}^{(4)}(x) \frac{1 \text{ GeV}^4}{Q^4}$, where functions $H_{L,2}^{(4)}(x)$ were the same for proton and deuteron, and parametrized similarly to $H_{L,2}(x)$. The fitted values of $H_{L,2}^{(4)}(x)$ are given in Fig. 2. One can observe the trend to the negative values at highest x for $H_L^{(4)}(x)$ and trend to the positive values for $H_2^{(4)}(x)$. However the statistical significance of the deviation of $H_{L,2}^{(4)}(x)$ from zero is not very large. In addition, the correlation of $H_2^{(4)}(x)$ with α_s and $H_2(x)$ is extremely strong. Summarizing these observations, we can conclude that the observed deviation of $H_L^{(4)}(x)$ and $H_2^{(4)}(x)$ off zero can be considered as qualitative only.

Any renormalization group analysis, which is based on the finite number of perturbative series terms is sensitive to the choice of renormalization scale. This dependence can be used for the rough estimate of the higher orders terms effect that are not accounted for in the analysis; if one includes all terms this dependence should vanish. For estimate of renormalization scale uncertainty in DIS analysis this scale usually is being chosen as $K_R Q^2$ and the value of K_R

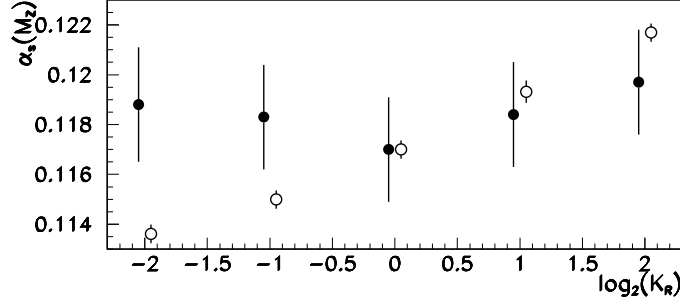


Figure 3: The dependence of $\alpha_s(M_Z)$ on the renormalization scale. Open circles correspond to the fits with the HT contributions fixed, full circles - to the fits with the HT contributions released.

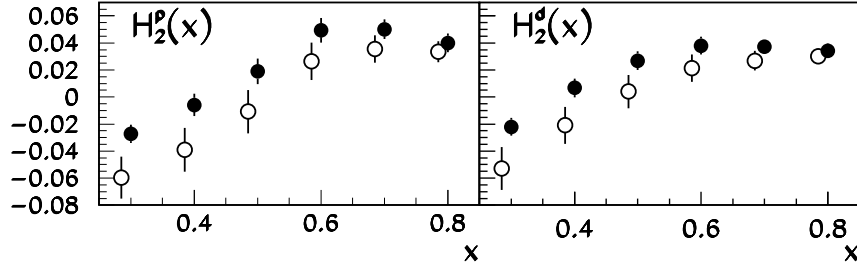


Figure 4: The values of HT contributions for $K_R = 0.25$ (open circles) and for $K_R = 1$ (full circles).

is varying in the range of 0.1–4.¹⁰ We studied the dependence of α_s on the value of K_R in two cases: for the HT contributions released in the fit and for the HT contributions fixed at the values obtained in the fit with $K_R = 1$. The results are given in Fig. 3. One can see that the dependence of α_s on the renormalization scale is different in the two cases. The reason of this difference is that the $H_2^{p,d}(x)$ are strongly correlated with α_s ; when one changes K_R , the changes in the QCD evolution kernel can be absorbed into the additional power-like contribution. This effect, illustrated in Fig. 4, can be considered as indirect indication that the fitted values of $H_2^{p,d}(x)$ can include not only genuine power corrections, but also effectively account for higher orders QCD terms. Any way the the value of α_s is quite stable against renormalization scale variation, if HT are released. At the same time the α_s errors are significantly larger for this case, which is also a consequence of the large correlation of α_s with HT, i.e. one can say that the uncertainty in the α_s value due to the renormalization scale choice is partially hidden in the total experimental error. The spread of the α_s value in the fits with $K_R = 0.25$ –4 and HT released is 0.0026. With the account of this spread we obtain $\alpha_s(M_Z) = 0.1183 \pm 0.0021(\text{exp.}) \pm 0.0013(\text{ren.scale})$.

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